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Coastal Erosion

In The Sandusky Bay Area

by

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Table of Contents

Table of Contents

(continued)

Introduction

Coastal erosion is a never ending process which deteriorates the shorelines of oceans and major lakes. The shoreline is an attractive area for residence, resorts and industries, but the shoreline is also a limited resource. Therefore, coastal erosion is another area where man is in battle against nature. To win the battle a closer look at the severity of the problem, its causes and some solutions and their impact is necessary.

This paper will focus on the coastal erosion along the southern shores of Lake Erie in Ottawa County. This area which I will call the Sandusky Bay area because it encloses the Sandusky Bay, includes Marble Head, Bay Point and Cedar Point (figure 1). Here the erosion problem is severe with shorelines retreating inland at a rate of 5 to 9 feet per year (Shaffer, 1951). The problem of erosion is always present because the unconsolidated material which makes up the shoreline is easily broken up and washed away by waves and other erosional agents. The net result is a loss of property and expensive maintenance cost. The rest of this paper will examine other factors involved in the erosional process of this area.

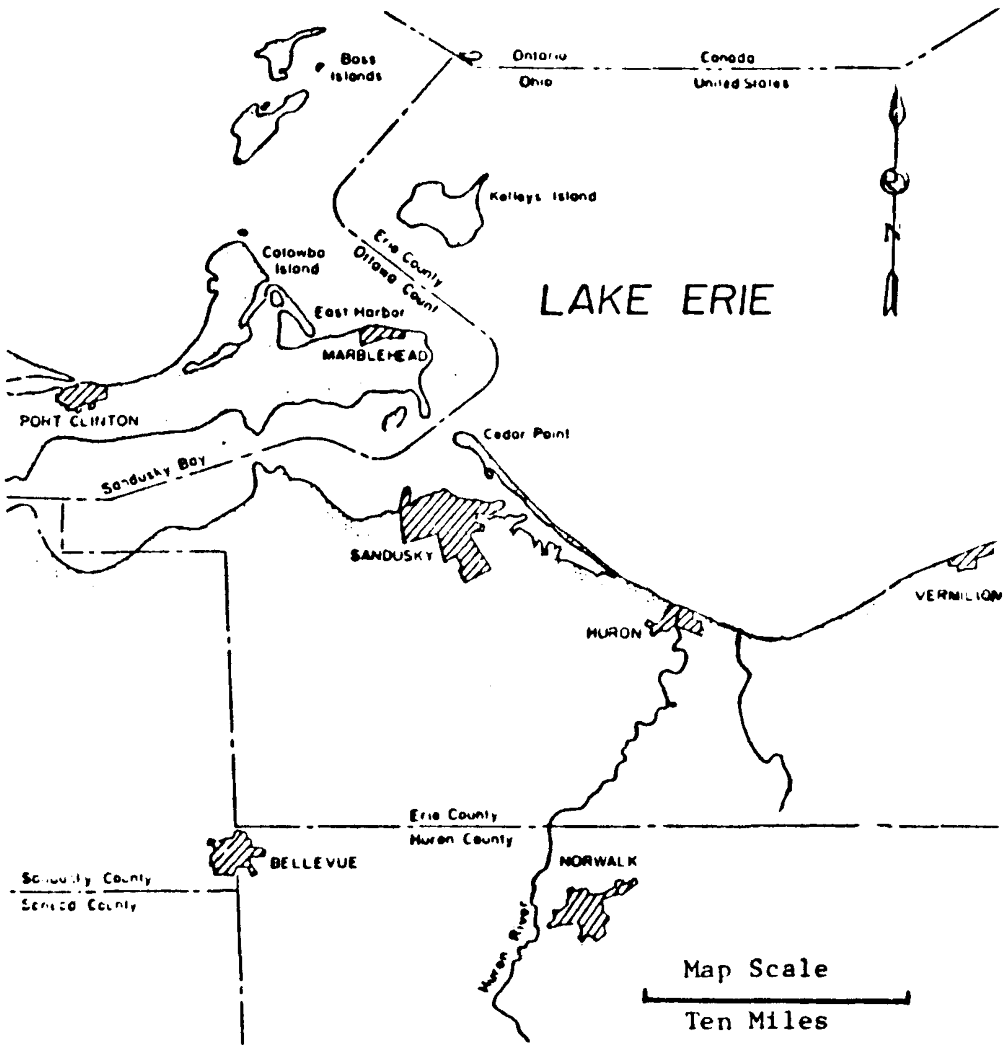

Figure 1 . Location Map (Modified from Worthy, 1980).

Erosional Factors and Their Effects

The erosional process has been broken down into three groups, the Environmental factors, the Geologic factors and the Human factors. Each group has a significant impact on the erosional process in this area. Each group will be studied in terms of processes involved and the role they play in the cause of erosion.

Environmental Factors

Wave Action

Waves play an important part in erosion by breaking away large chunks of bluff material. Under normal conditions waves break far offshore and the energy is dissipated through refraction of the wave with the shore. However under storm conditions things change, now waves are breaking onshore or even against the bluff itself. When a wave breaks against a sea wall or bluff thousands of tons of water are in motion against the structure. Shock pressures of 12,700 lb/ft^2 have been measured on sea walls. Although the duration of each shock is only a fraction of a second, constant pounding by waves can pry loose large blocks of material. The highest waves seem to be from the west-northwest direction as seen in Figure 2. Existing groins, breakwater, blocks and debris offer protection by dissipating the wave energy.

Wetting of the bluff either directly by waves or by spray can cause a decrease of cohesion between the clay minerals in the bluff. Cycles of wetting and drying cause cracks by shrinkage, exposing more of the bluff to other erosional agents.

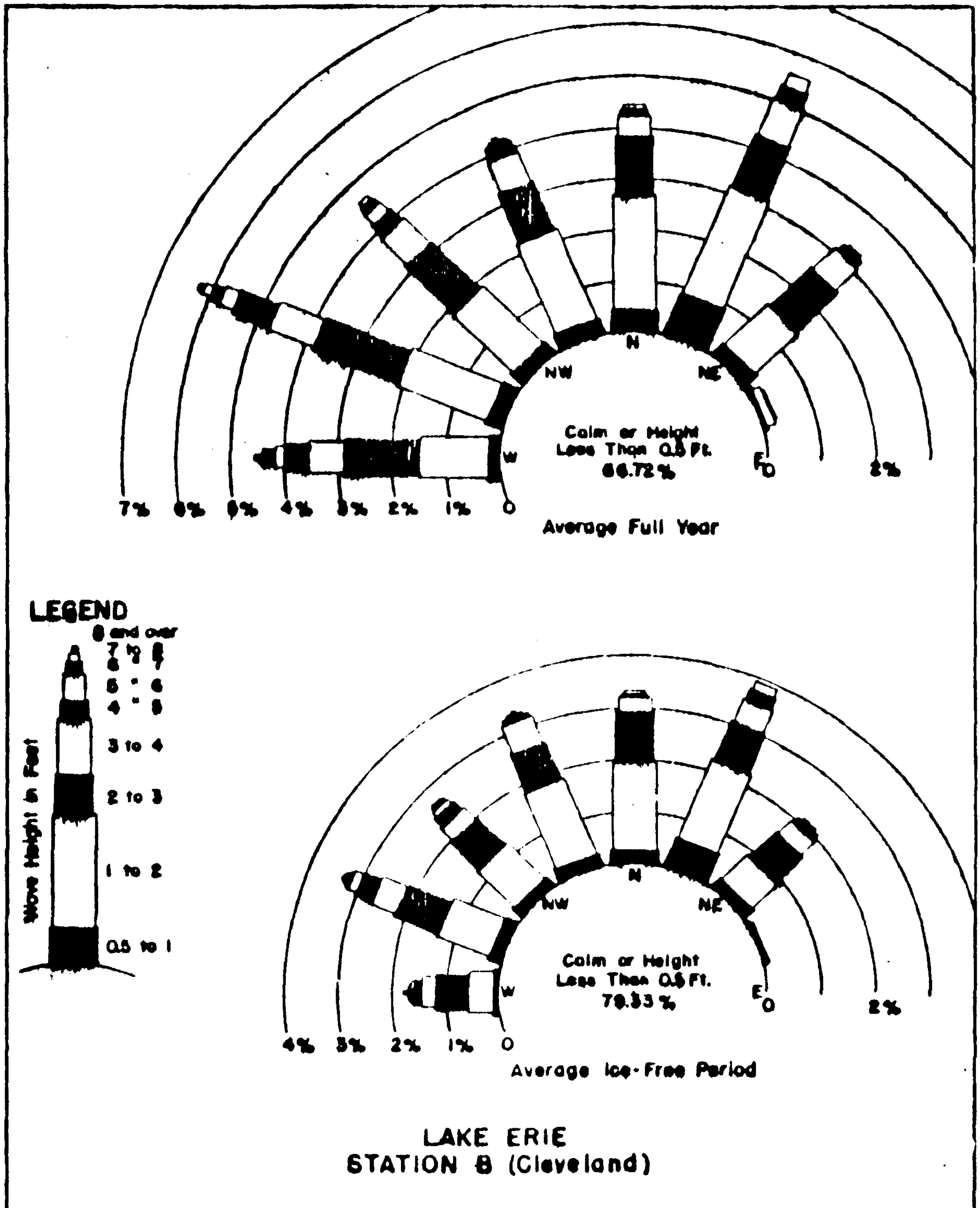

Fig. 2 WAVE ROSE SHOWING PERCENT OF TIME WAVES OF DIFFERENT HEIGHT OCCUR FROM EACH DIRECTION

(Copied from Chieruzzi, R., 1951)

Ice and Frost Action

Ice and frost action is a major contributor to shore erosion. This happens in many ways. First in fine-grained silty types of soil found along the shores of Lake Erie, just the act of repeated freezing and thawing alone can weaken the soil to the point where flowage takes place. In more durable clays, frost and ice will grow in fissures breaking off large blocks or opening the fissures to other means of erosion (Hyland, 1959). Also in clays and tills the action of frost heaving takes place. Frost heaving is the displacement of soil due to the expansion that takes place when the pore water turns into ice crystals. The direction of heaving is outwards and perpendicular to the slope. In thawing the soil does not return to its original position. During thawing there is more water added to the clays. This causes a reduction in the cohesive forces and frictional forces. This weakened clay along with gravity causes the soil to move down slope (Chieruzzi, 1957).

Frost and ice action also affects the argillaceous bedrock in this area. In this case its not the frost or ice causing the deterioration but expanding water. Water with clay becomes highly ordered. This is so because the negatively charge clay attracts the positive charge hydrogen side of water. This bond that is formed is stronger than the bonding force in ice, therefore, the water becomes nonfreezable. This nonfrozen water actually expands when cooled to -20^{0} or -30^{0} centigrade, exerting a force on the area around (figure 3). Ice, when cooled to -20^{0} or -30^{0} centigrade, contracts more than the rock and is not capable of exerting this force on the rocks at this temperature (Dunn and Hudec, 1966).

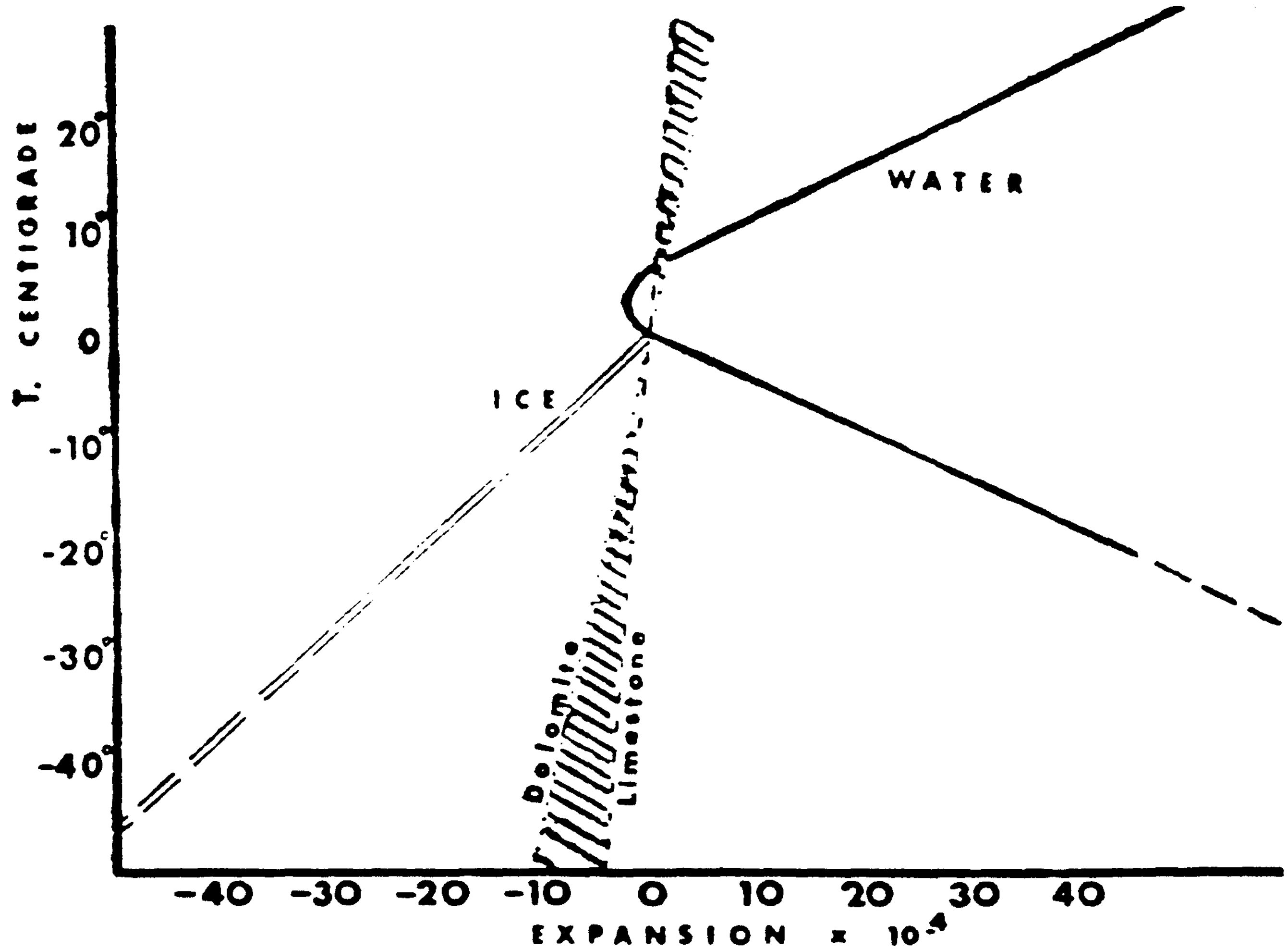

Figure 3. The effect of low temperatures on ice, carbonate rock, and water (from Dunn, J.R. and Hudec, P., 1966).

Ice Shove

Ice shove is responsible for the removal of sand from the beach. During cold winters Lake Erie is partially or completely covered by ice. In the winter of 1977-78 Lake Erie was 100% covered by ice throughout February and into March (Dingman, 1980). This ice is broken up and driven onto the beaches by storms. While on the beach, the ice picks up sand and other materials. Later, winds blow these sand-laden ice sheets out into the lake. Here they dump the beach material far offshore.

Lake Levels

Lake levels play an important part in erosion. Lower lake levels allow the waves to break safely offshore. A high lake level makes the waves break at the toe of the bluff causing much damage to this area. Every body of water has these water-level fluctuations. These can be divided into two groups: the long period or seasonal changes and the short period.

The long period fluctuations are related to precipitation, evaporation and runoff. The high and low peaks will change with the season. The maximum lake level in June when runoff is the greatest and the minimum lake level in February when all the water is tied up in ice and snow. The average of these fluctuations is around 1.5 feet (Dingman, 1980).

Short term fluctuations are caused by changes in wind velocity across the water, changes in barometric pressures across the water from one side of the lake towards the other, similar to soup sloshing in a bowl. There are two types of short term fluctuations, one is free oscillation, known as seiche and the other is forced oscillation called storm surge.

Lake levels can be increased or decreased as a result of changes in atmospheric pressure. Studies show that a one millimeter change in atmospheric pressure produces an inverted effect of 14.7 millimeters in the level of the lake (Dingman, 1980). Steep pressure gradients that accompany cyclonic storms can produce forced oscillation of several feet or more in Lake Erie.

Forced oscillation produced by wind affects the lake by blowing the water from one end of the lake and piling it up at the other end. Recent studies on Lake Erie show that the wind effect on the lake level is much greater than the atmospheric pressure changes. There are two reasons for this, first the longitudinal axis of Lake Erie runs west-southwest to east-northeast, the same direction as the predominant wind. Therefore more momentum can be transferred from the wind to the lake producing a higher wave setup. The second reason for greater wind effect on Lake Erie is due to the shallowness of the lake. The average depth of Lake Erie is only about 60 feet. Because of its shallowness, the momentum transferred from the wind to the water will act throughout the depth of the lake causing the whole volume of water to be in motion (Dingman, 1980).

Forced oscillations can also be produced by the resonance coupling between a moving atmospheric disturbance and a body of water. Resonance occurs in shallow water when the disturbance above and the wave below travel at the same speed. This allows the energy from the disturbance to be transferred to the wave causing the wave to grow (Bretschneider, 1967). In theory the wave can grow to infinity, however complete resonance will not occur because of frictional effects and other factors.

Free Oscillation

Free oscillation or Seiche is present all the time and is caused by variations in meteorological conditions, the earth's rotational spin causing the lake to experience the Coriolis effect, and gravitational pull of the sun and moon. The result is the rhythmic motion of the water surface. This rhythmic motion is observed to have nodal lines and ventral lines. The nodal line is the point or line where the water level is unaltered during the whole period or one complete oscillation. The ventral lines mark the highest elevations during an oscillation. A uni-nodal seiche has one nodal line in the center and two ventral lines, one at each end. The motion of the water surface during a uni-nodal seiche starts with the rise of water level at one end of the lake and a simultaneous lowering at the other end and vice versa. A binodal seiche has two nodal and three ventral lines, and the water level rises simultaneously at both ends while the middle is depressed. A trinodal seiche has three nodals and four ventrals and so on. In every lake seiche of any number of nodals is possible. Lake Erie has seiches of four nodals. Studies have been done to measure the time between the pass of each nodal line on the shores of Lake Erie. The time between each nodal line on Lake Erie is, in hours, 14.3, 2.7, 5.7, and 4.14 (Hellstrom, 1941).

Forced Oscillation

Forced oscillations or storm surges are super imposed on free oscillations and are usually several times larger than free oscillations. Forced oscillations are caused by the combination of pressure changes, wind effect and resonant coupling.

Geologic Factors

Bedrock Geology

The bedrock in the Sandusky Bay area consists of the Salina Group, the Bass Islands Dolomite and the Detroit River Formation. The Salina Group consists of mostly argillaceous dolomite with shales and anhydrites. The group is broken into seven distinct units and labeled A through G. The complete section is found in Erie, Huron and Richland Counties. However in Sandusky, Ottawa and Seneca Counties the Salina unit becomes undifferentiable and is truncated by pre-Devonian unconformities. The Salina in the Sandusky Bay area consists of the Greenfield Dolomite, the Tymochtee Dolomite and the Undifferentiated unit (Janssens, 1977). The Salina Group is of Silurian age.

The Bass Islands Dolomite is of upper Silurian age and differs from the Salina Group by the lack of anhydrite. Some authors try to divide the Bass Islands Dolomite into the Put-in-Bay and the Rasin River; however, this division is not necessary because the two groups are difficult to differentiate and the faunas of the two are not distinctively different (Sparling, 1965). The Detroit River Formation is of Devonian age and lies unconformably on the Silurian rock below. The Detroit River Formation is divided into four members however, only the Amherstburg and the Lucas members will be studied in this paper (Figure 4).

The section of the Salina Group seen in Erie, Huron and Richland Counties is an excellent reference section for study comparison of stratigraphic and depositional changes. The Salina consists of alternating layers of dolomite, anhydrite and shale and has an average thickness of 600 feet. A description of the units of the Salina Group follows:

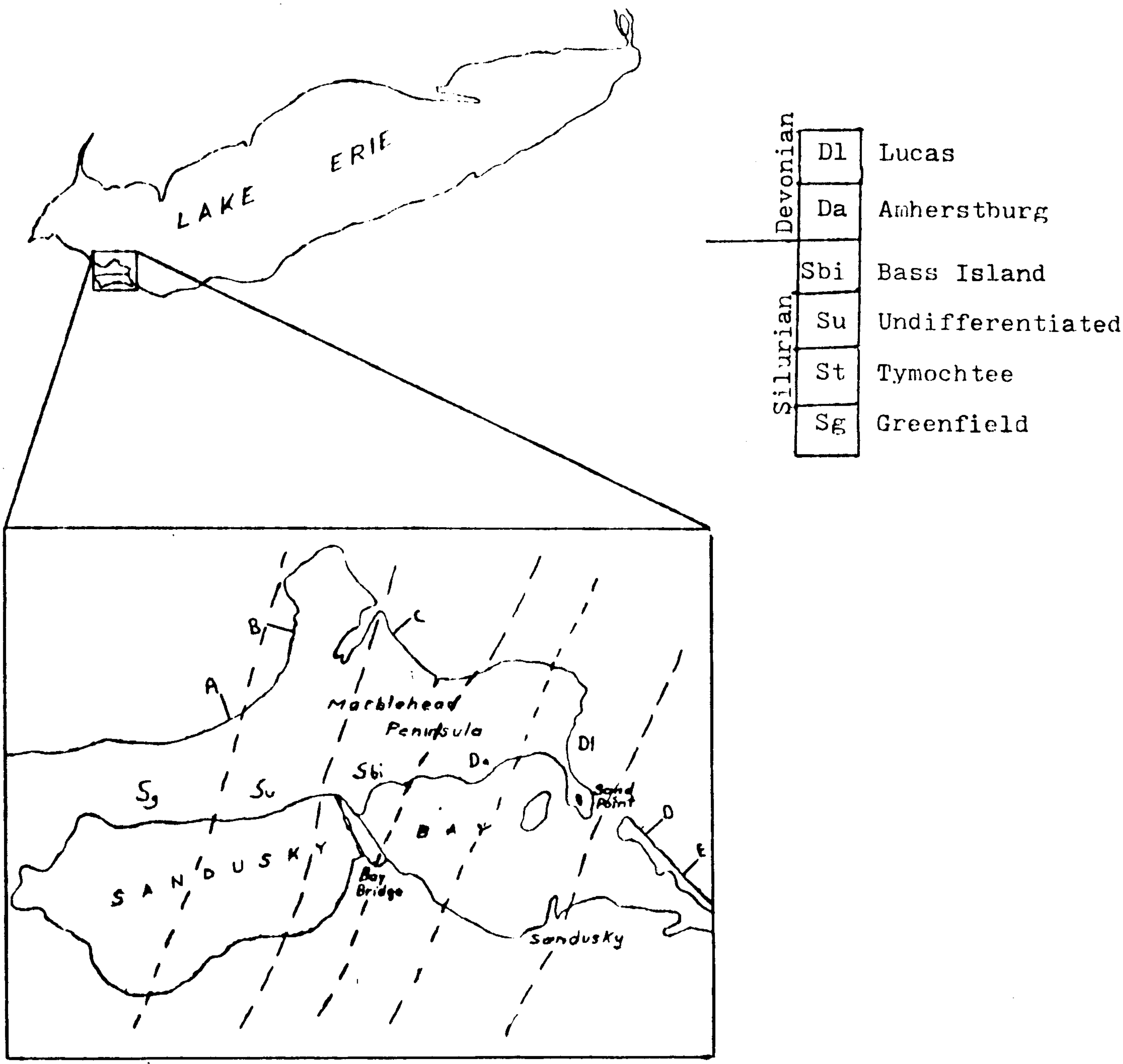

Figure 4. Geologic Map of Sandusky Bay Area (modified from Pincus, H.J., 1953 and Sparling, O.R., 1965). Single letters (A, B, C, D, E) indicate shore profile locations.

Unit A

The A unit of the Salina is divided into the A_1 Anhydrite, the A_1 Carbonate, the A_2 Anhydrite and the A_2 Carbonate. The A_1 Anhydrite ranges in thickness from 5 to 35 feet and is dolomitic in parts. The A_2 Anhydrite is much the same in thickness and description. The A_1 Carbonate consists of microcrystalline, slightly anhydritic, medium and dark-brown dolomites. The A_1 Carbonate ranges in thickness from 25 to 63 feet with an average of 45 feet. The A_2 Carbonate is much the same in description, however the thickness ranges from 75 to 110 feet with an average of 85 feet.

Unit B

The B unit consists of interbedding salts and shales. This unit thickens towards the west where the salt is replaced by anhydrite and the shale becomes more dolomitic. The thickness of the unit ranges from 65 to 117 feet and averages 85 feet.

Unit C

The C unit consists of anhydritic silty argillaceous greenish-gray dolomite that grades into shale. The unit contains very fine to medium grained, rounded, frosted Quartz sand which is scattered about within the unit. These distinguishing grains make this unit a reliable time-stratigraphic marker. This unit ranges in thickness from 50 to 110 feet and averages 80 feet.

Unit D

Unit D is not recognized in this area.

Unit E

The E unit consists of anhydritic microcrystalline brown dolomite and argillaceous microcrystalline brown dolomite with thin anhydrite beds. The top 10 to 20 feet of the unit is always composed of very argillaceous dolomite or shale. The thickness of the unit ranges from 69 to 113 feet and averages 90 feet.

Unit F

The F unit contains a series of anhydrite, anhydritic brown dolomite and dolomitic dark gray shales that grade into dolomite. The anhydrite in the unit is altered to gypsum towards the west. The thickness of the unit ranges from 66 to 93 feet.

Unit G

The G unit is divided into the lower and upper units. The lower unit is an argillaceous microcrystalline gray to dark green dolomite. The upper unit consists of dolomitic anhydrite. The dolomite is replaced by gypsum towards the west. The thickness of the unit averages 75 feet (Janssens, 1977).

The Salina Group in the Sandusky Bay area differs from the reference section by losing salt and anhydrite beds and by the individual units becoming undifferentiated. The members of the Salina Group in the Sandusky Bay area are the Greenfield Dolomite, the Tymochtee Dolomite and the Undifferentiated Dolomites (Janssens, 1977).

Greenfield Dolomite

The Greenfield Dolomite is a microcrystalline, light yellow to medium brown dolomite with carbonaceous streaks. There is a stromatolite facies which is a minor feature and generally not found in well samples. The thickness ranges from 30 to 97 feet. The contact between the Greenfield and the Tymochtee above can be correlated to the contact between the A_2 Anhydrite and the A_2 Carbonate found in Erie County.

Tymochtee Dolomite

The Tymochtee Dolomite is a microcrystalline light to dark-grayish-brown argillaceous dolomite and contains shaly black partings. Thin beds of microcrystalline medium-brown dolomite are common in this unit. Quarries in Wood County show layered gypsum nodules near the base. The thickness ranges from 122 feet in the east and thins to 0 feet in the west. The thinning corresponds to the increase of thickness of the underlying and overlying rocks.

Undifferentiated Dolomite

The Undifferentiated Salina consists of the rocks which overlies the Tymochtee Dolomite. Within the undifferentiated unit are recognized two marker beds which correlate to the C and E units. The Undifferentiated Salina consists of microcrystalline light to dark brown and yellowish brown argillaceous dolomite with laminations and pellets. The C unit which is recognized consists of a light gray and greenish-gray argillaceous and silty dolomite that grades into shale. The shale contains frosted Quartz grains. The E unit that is recognized has a very argillaceous zone of 10 to 30 feet thick and lies 60 to 110 feet above the C unit (Janssens, 1977).

Bass Islands Dolomite

The Bass Islands Dolomite is a microcrystalline light gray to light and medium brown dolomite that locally contains traces of chert. Early reports subdivide the Bass Islands into two members, the Put-in-Bay and the Rasin River. However, recent studies find it difficult to subdivide because of difficulties in differentiating the members. Therefore the Bass Islands is of upper Silurian age and the average thickness is 55 feet (Janssens, 1977).

The Detroit River Formation is of lower Devonian age and lies unconformably on the Bass Islands Dolomite. The members of the Detroit River Formation which are studied in this paper are the Amherstburg Dolomite and the Lucas Dolomite.

Amherstburg Dolomite

The Amherstburg Dolomite is a thick bedded light brown to gray colored, porous dolomite with quartz sand included. The range in thickness is from 84 to 170 feet, thickening towards the north.

Lucas Dolomite

The Lucas Dolomite is a light buff to gray crystalline dolomite with crystals of calcite and frosted quartz sand. The average thickness of the Lucas Dolomite is 29 feet (Ehlers, Strumm and Kresling, 1951).

The major structure in the area is the Findlay Arch, the axis of which lies just west of here and runs north-northwest. The Sandusky Bay area lies on the east flank of the Findlay Arch. In this area most of the bedrock is covered by glacial tills and lacustrine clays. Water wells in this area report tills and clays being as thick as 25 feet (Sparling, 1965). Because of the argillaceous nature of the rocks in this area, frost action and wave action may be the active erosional agents in this area.

Littoral Transport

Littoral transport is the movement of sediment in the Littoral Zone by waves and currents. The movement is in two directions, parallel to the shore, called longshore transport and perpendicular to the shore called on-offshore transport. The direction of longshore transport can vary from season to season or even hour to hour. Longshore transport is caused by waves hitting the beach at an oblique angle and moving the material on the beach in the direction of the wave. In the Sandusky Bay area the predominate direction is from the southeast.

The on-offshore transport helps to shape the beach and giving the Littoral Zone its profile. On-offshore transport is responsible for the grain size distribution along the profile. This transport is caused by wave action with the large storm waves causing the offshore movement and the gentle swells causing the onshore movement.

Littoral transport effects erosion by removing material from the beach. With on-offshore process material is usually conserved because the material is only shifted back and forth in the surf zone. Material is only lost if it is carried far offshore and into underwater canyons.

Longshore transport is continually moving material down drift. The material moved out of one area is being replaced with material from updrift. This cycle continues until the source updrift is choked off (Worthy, 1980). In this case, the material is carried out of an area without being replaced. The beach will begin to marrow allowing the waves to break close to the bluffs.

Another agent of erosion by littoral transport is abrasion. Sand particlues and other material carried by the longshore transport acts a tools to cut and remove material at the toe of the bluff.

Beach Profile

The Beach Profile is a cross sectional view of the beach. Such a view shows the width and slope of the beach and shore areas which is useful in determining beach stability. A wide, gently sloping beach is more stable than a narrow, steep beach (U. S. Army, 1979). This is because a wide beach has the waves breaking far offshore and the wave energy is completely dissipated before reaching the bluff. A narrow beach has the waves breaking at the toe of the bluff and the wave energy is released directly against the bluff.

The slope of the beach is also important in beach stability. A gentle sloping beach produces breaking waves of less energy. A steeply sloping beach also has greater littoral currents. Greater littoral current has more abrasion resulting in rapid decay of the bluff.

Some profiles are given on figure 5, and their approximate location shown on the map of figure 4. Profile A on the west flank of Marble Head Pennisula shows a nearly flat beach of moderate to narrow beach.

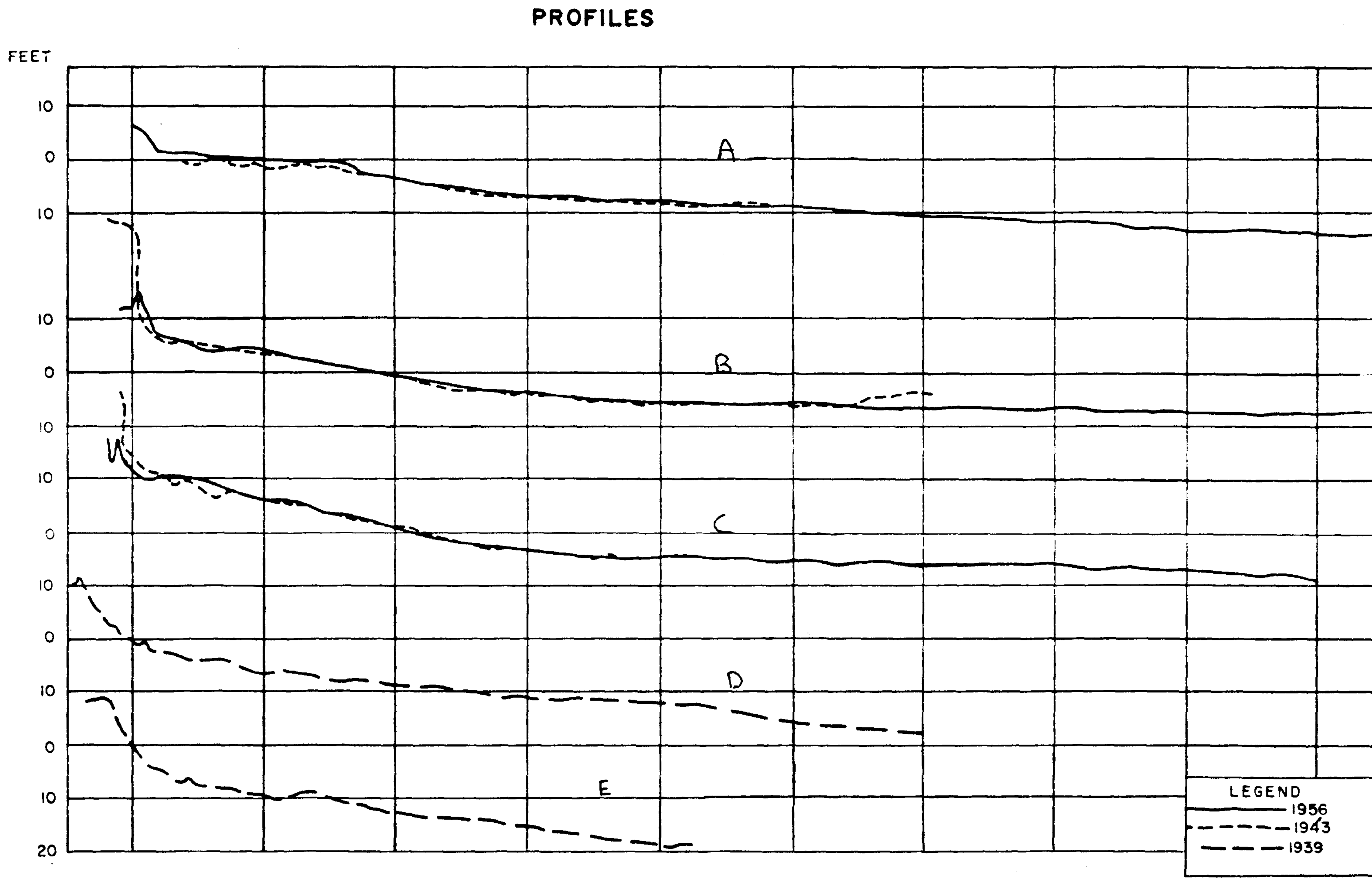

Figure 5. Shore Profiles (from Pincus, H.J., 1960).

This section of beach is fairly stable, but because the beach is so level and narrow a slight rise in the lake level may put the waves against the bluff.

The profile of B on the western side of Marble Head Pennisula and profile of C on the eastern side are very similar. Both show a stable beach with a wide beach of gentle slope. This area will experience little or moderate erosion.

The profiles of D and E are also much alike. They both show little or no beach and steep banks. This allows for large waves to break directly against the bluff. This area will experience severe erosion.

Bluff Material

The bluffs are the steep cliffs of unconsolidated material at the beach's edge. The unconsolidated material in this area is about 70 feet thick with the bottom 20 feet being till and the top 50 feet of lacustrine clay (Palombo, 1974). This bottom layer was deposited as glaciers advanced through this area. These glaciers also left ridges of till which dammed up rivers and other drainage to form a giant glacier lake of which Lake Erie now occupies. This giant glacier lake once extended as far south-west as Fort Wayne, Indiana and left a deposit of clay over this entire area. The lacustrine clay is a fine-grained, bluish-gray silt and clay with brown mottlings. The deposit varies from massive to bedded. The clay is often jointed and becomes crumbly by frost action. The waves remove this crumbly outer surface exposing a new surface to the same process. The eroded material from the bluff contributes nothing to the beach because of the lack of sand in the bluff material (about 2 percent) (Janssens, 1977). Therefore much of the material from the bluffs is simply washed away.

Human Impact

Existing Structure

There have been many structures built along the shores of Lake Erie. Most of these structures were built by individual land owners hoping to protect their property from further erosion. These ended up being minor structures with no coordinate plan of protection, poorly designed and as a result had little effect on the shoreline. However the Cedar Point Jetty is a major structure with significant impact on the shoreline.

The Cedar Point Jetty was built by the United States Government to keep the entrance channel of Sandusky Bay clear of sand. The Cedar Point Jetty has a length of 6000 feet and the impounding sand extends for about 2 miles eastward from the Jetty (House Document 177). A jetty is a wall built perpendicular to the beach. Jetties are used to trap the sand carried by littoral transport so that this material does not settle and clog a channel. Jetties also stop the littoral transport cycle so that the beach down drift is deprived of sand (U. S. Army, 1977).

Residence and Resorts

The number of residence and resorts has been increasing in this area. With the increase in the number of structures built on the shores comes an increase in the weight added to the bluff. This increase of weight on the bluff causes an instability, making it prone to slumping. Paths from the residence leading to the beach also helps the slump processes. Sewage and septic tanks add water to the bluff also causing mass movement.

Solutions

There are basically four solutions for the coastal erosion problem. The first solution is to keep the beaches nourished with sand. This has a two-fold effect. First it keeps the littoral cycle operating by providing a constant supply of sand, and secondly the nourished beach absorbs the energy of the waves and adds material between the bluffs and the lake. This is accomplished by beachfill. The advantages of beachfill are its pleasing appearance and its recreational value. However because the beachfill material is constantly being carried away by littoral drift, periodic nourishment is needed. Therefore its disadvantages are that it requires an adequate supply of sand and it needs continuous renourishment.

The second solution is to keep the shoreline or bluff from retreating anymore. This is accomplished by protecting the bluff from wave action through sea walls. Sea walls provide a barrier between the sea and the land. The advantages of this are that it maintains a steady and fixed shoreline, and the shoreline is well protected and able to handle more intense use. The disadvantages of sea walls are that they do not maintain a beach, that is, everything lakewards of the wall may be lost to the lake. They also do not protect adjacent property. The area on either side of the wall may erode and expose the flanks of the protected property. A third disadvantage is the sea wall is subject to failure due to undermining.

A third solution is to build up the beach. This is done by trapping sand with a groin. A groin is a wall-type structure built perpendicular to the beach to retain material moved by littoral drift. The advantages of groins are that the resulting beach provides protection for the area and provides a recreational area, the effect may be spread over a long length of shore and the initial cost is lower. The disadvantages are the protection given is not as great as the protection by sea walls or breakwater. They are ineffective where there is a small amount of material moving along the beach. And the down drift area is deprived of material resulting in accelerated erosion.

A fourth solution is to reduce wave action along the beach by stopping the waves at sea. This is done by offshore breakwaters. Breakwaters are structures built offshore to absorb the wave energy before the wave hits the beach. The advantages of breakwaters are they make a stable beach line which provides adequate protection, they provide a recreational area, and they can extend for long distances providing protection for a long stretch offshore. The disadvantage is that the beach line will take on a curved alignment (Sweeney, 1973).

Conclusion

Erosion is a difficult problem with many factors involved. Most of these factors cannot be controlled by man such as ice and frost action, ice shove, lake levels, bedrock and bluff material. Other factors cannot be eliminated, but they can be controlled by man to minimize the erosional effect. These include wave action which can be reduced by the use of breakwaters and littoral drift which can build up a beach if a proper groin system is in place. And beach profile can be altered by beachfill. For a problem as complex as coastal erosion there may not be a one clear answer, but a possible solution can be obtained by a combination of ideas. For example, the area of beach left barren by the interruption of littoral transport by the Cedar Point Jetty can be built up with a beachfill. To slow down the rate of removal of the beachfill a breakwater should be built. This breakwater should be well marked and placed so as not to interfere with shipping traffic in and out of the Sandusky Bay.

Even with man's best efforts to stop coastal erosion, because of all the factors involved, erosion continues.

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